Wearable Computers for NASA Applications[1]

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Abstract – At the Goddard Space Flight Center, members of the Real-Time Software Engineering Branch are developing a wearable, wireless, voice-activated computer using many off-the-shelf components. This will be used in a wide range of crosscutting space applications that would benefit from having instant internet, network, and computer access with complete mobility and hands-free operations. These applications can be applied across many fields and disciplines including spacecraft fabrication, integration and testing (including environmental testing), and astronaut on-orbit control and monitoring of experiments with ground based experimenters. To satisfy the needs of NASA customers, this wearable computer needs to be connected to a wireless network, to transmit and receive real-time video over the network, and to receive updated documents via the Internet or NASA servers. The voice-activated computer, with a unique vocabulary, will allow the users to access documentation in a hands-free environment and interact in real-time with remote users. We will discuss wearable computer development, hardware and software issues, wireless network limitations, video/audio solutions and difficulties in language development.

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1. INTRODUCTION

As the world becomes increasingly dependent on computers, more applications can be found which would benefit from the development of smaller, faster computers, video products, and audio products that are capable of being worn by the user. The era of the next generation of personal and business computers is rapidly approaching. This allows for mobile computing not only in a lab setting, but also in that of the real world. These smaller, more powerful computers, coupled with cameras and microphone technology, allow communication and collaboration with others while working on a task. The potential benefits are evident in areas such as clean rooms, space shuttle checkout [Bently02], pre-launch checkout and on-orbit activities [Bently03]. Wearable computers will become strategically important to NASA for many uses including collaboration. A single technician could provide a live video stream of her activities via the web while performing tasks that require the use of her hands. Experts could share their knowledge with her from anywhere in the world. This would contribute toward the goal of reducing the number of people required in a clean room, around a thermal-vacuum chamber and in other situations requiring video/voice conferencing and hands-free operations. A single expert could monitor (and instruct) multiple technicians even when they are deployed to different areas, all via video/audio streams over the web. This would integrate computers and humans working in diverse geographical areas. A voice-activated computer would allow a technician to annotate the steps completed in a procedure, document any procedural changes, and send those changes to others participating in the activity. Also if a new procedure were made available, it could be accessed via the voice-activated computer over the wireless network. Astronauts could use small, light wearable computers to reference procedures and manuals, while keeping their hands free to perform their work. They could also communicate with experts on the ground with this device, alleviating the need to find/grab an off-body microphone. In many cases, the electronic drawing board (which all parties could see) could be used for communicating detailed descriptions. Specialized verbal languages aiding the speech interface to the computer will enable these activities to occur smoothly.

Kennedy Space Center representatives have expressed interest in this project and the possibility of using wearable computers for both space shuttle tile [Bently01] and main engine checkouts. Currently, technicians use a digital camera to take pictures, then, when finished, email them to experts. Once the expert receives the pictures, it may be too late to see other angles. A technician with a wearable computer could be guided to the best views by remotely located experts. The experts could pick out damaged spots more reliably than could the technicians. The video and still shots would be seen in real-time while better views could still be acquired. Better safety and design related decisions could then be made. The video and still shots could be archived for future reference.

With all these applications in mind, the Wearable Voice Activated Computer (WEVAC) Project was initiated, with minimal funding and with part-time efforts of the personnel involved, to develop and test out a wearable computer. The initial system needed two software components. First, speech recognition software was needed in order to free the user's hands as much as possible while using the computer. Also, collaboration software was needed to enable conferencing and collaboration amongst users. For hardware, the system needed a CPU, a camera, a microphone, and a display system. All of these components had to operate using batteries.

The focus of this project is to investigate the current state-of-the-art in both complete wearable systems and systems integrated from individual components. We want to see which elements of the systems are ready for use and which elements need to evolve. We hope to drive or at least encourage the manufacturers of these components to create the devices with the features that NASA needs. We want to see how language and collaboration software will improve functionality as well. At Goddard Space Flight Center, there are several environments where a hands-free, wearable, wireless, voice-activated personal computer would be a desirable device to have. The goal is to integrate a WEVAC that is suitable for some of the work that goes on at Goddard and NASA as a whole. To that end, we are working with personnel at Goddard Space Flight Center, Kennedy Space Center and Johnson Space Center. The goals for WEVAC's future include testing how well one would perform in spacecraft testing, inspections, and collaboration environments using NASA applications.

2. Work Accomplished

The first considerations were complete systems, including the Xybernaut Mobile Assistant IV, the Microvision Wearable Display System, ViA, The Computex Taipei 2000, and the SyVox Speech Data Terminals. We saw demonstrations of the Xybernaut systems in particular. These are very good systems, and they fired up our enthusiasm and convinced us that this technology will transition from the research lab to mainstream use within a matter of years. Since our research (gleaned from Gartner Group and other visionary groups) indicates that this architecture will replace a majority of desktop and laptop systems, we expect that NASA will be buying systems from these companies or similar ones in the future. For our research effort, however, we did not choose to buy a complete system for two primary reasons. First, the CPUs clock speeds in the complete systems were only about 200MHz – we needed more CPU power for video applications. Second, we thought we'd learn more about each component by researching the individual markets, buying the best we could find, and integrating them ourselves.

So, the work accomplished on the WEVAC project entailed researching, procuring, and testing available software and hardware components. We first researched the different speech recognition and collaborative software available. Once the best packages were identified, we began to research the hardware. This involved researching the specifications of different units, price, and other factors. After components had been purchased, they were put together as prototype units. We then tested how well these units performed in work-like conditions. One sizeable task is to create a grammar set that the speech recognition software can recognize and execute successfully. This will be accomplished through research in the programmable portion of the software and through the employment of a software development kit. Another task was employing wireless networking into the units to make the unit mobile. This, coupled with having to fashion a battery in-house for one of the units, proved to be another challenging task. To make the battery pack, two smaller commercial batteries were linked together from a suitable power source. The prototype unit had shortcomings, but provided useful insight into the future of wearable personal computers and to our endeavors.

Our initial goals for the first prototype were:

1) Assemble a wearable, wireless, voice-activated computer.
2) Research collaborative and speech recognition software for use with this unit.
3) Demonstrate the operability of a WEVAC.
4) Study the human interface factors by using such a unit.

To accomplish these goals, we performed many tasks including:

1) Installing, testing, and analyzing collaborative and speech recognition software packages
2) Researching the components that would comprise a prototypical WEVAC
3) Ordering, testing, and analyzing the WEVAC.
4) Documenting progress and the advances of the project overall

3. Speech Recognition Software

As stated above, in order to achieve a completely wearable device with hands-free operation, the system must have robust speech recognition capability. Therefore, several speech recognition packages were tested. The goal for this type of testing was to discover the best package to use with the prototype unit in NASA environments. The criteria for inclusion in our testing were that the packages had to be commercial-off-the-shelf, have general acceptance in the industry and have a developer's kit available. Based on this, three packages were chosen for testing: Dragon Naturally Speaking, L&H VoiceExpress, and IBM ViaVoice. Several members of the WEVAC team tested these packages for the ability to recognize many users' speech with minimal error, and at times with background noise. This would enable the users to reliably manipulate the desktop in a somewhat customary manner. See the results in the table below. ("Free speech" refers to a mode in which the speech algorithm is "listening" for any word in the vocabulary, rather than "listening" for one of a small set, as when listening for the words on a menu.)

The evaluation factors are shown in the table below:

WEVAC Speech Recognition Software General Ratings

Averages from surveys

(Values in minutes are not added into the total)

Test (Most will be rated from 1 to 10)	**IBM**	**L&H**	**Dragon**
Installation time (in minutes)	6 minutes	6 minutes	5 minutes
Impact to overall speed of machine (1=very slow)	5	6	5
Amount/Frequency of Disk Access Required (1=a lot of access)	5	6	5
Installation difficulty (1=very difficult)	9	8	9
Installation clarity (regardless of the time or difficulty) (1=very unclear)	9	9	10
Training Process Time (in minutes)	64 minutes	30 minutes	50 minutes
Training Process Difficulty (1=very difficult)	8	9	7
Ease of use (1=very difficult)	6	5	5
Free speech accuracy in quiet conditions (1=very inaccurate)	5	6	5
Free speech accuracy in more noisy conditions (1=very inaccurate)	5	5	5
Use of the menus in a package (like MS Word - 1=very inaccurate)	7	8	6
Vary your voice from low to the high (1=it could not understand when voice is altered)	5	6	5
Ease of using Windows directly (1=very difficult)	6	8	5
TOTALS	**70**	**76**	**67**

The specific phrases in the table below were used to equally compare the packages' ability to understand phrases that might be used in a NASA environment.

WEVAC Speech Recognition Software Specific Phrase Ratings

Averages from surveys

Please repeat the following phrases (Scale: 1-Very inaccurate to 10- Very accurate)	**IBM (1 to 10)**	**L&H (1 to 10)**	**Dragon (1 to 10)**
Undo the last step	7	6	8
Go to Page 53	5	7	7
Find annex A	3	6	4
Step 46 completed	7	7	7
Sheet 21, move to right	4	4	3
Next page	8	9	10
Drawing 10 zoom in	4	6	4
Close book	2	7	8
Undo the last step, go to page 53 and find annex A.	3	7	5
Step 46 completed, move sheet 21 to the right.	7	6	6
Next page, open drawing 10 zoom in and close book.	2	4	4
TOTALS	**52**	**69**	**66**

Overall, L&H VoiceXpress received the highest ratings using the evaluation factors. Thus, it was chosen as the speech recognition software to be used in conjunction with the wearable computer. However, it should be noted that none of the speech packages provided the accuracy needed to enable a user to be completely hands-free. The basic vocabulary set provided in the speech packages was large, requiring the speech recognition engine to distinguish among many words. This situation frequently prevented the capability of going to a particular spot in the document. It also made emailing, documenting, annotation and other forms of "free speech to text" difficult. All of the testers 'trained' the speech recognition software before exercising the test phrases. The two general problems with the training programs were inability to keep up with the speaker's natural speaking speed, and inadequate word recognition. These were very frustrating to the testers. The age and gender of the tester made a difference in the training results; however a pattern could not be validated without a much larger group of testers.

All three packages were sensitive to varied background noise. The pitch of the background noise also made a difference. The general office and facility noises, except a loud air conditioner, did not seem to impact any of the software packages. One of the portable computers had a fan that seemed noisy, which influenced the initial noise checks and caused more failures than were exhibited on a different computer.

All users reported that free speech accuracy was poor to unusable. Most users also reported that the mouse and keyboard would be preferred at all times over the speech recognition software. In free speech mode failure rates as high as 80% were reported. All had problems with high failure rates. The failures included misspelled words, missing words, and additional words. In many cases, varying the tester's voice changed the accuracy rate. This could be important because individuals normally do not talk in a monotone voice in a real world environment.

Each package performed well when specific and limited word sets were used. This was the case when navigating the computer file system and using certain applications of which the speech package was aware. An example of a limited word set might be: file, open, close, exit, etc. However the testers reported quicker responses by using keyboard or mouse.

Some examples of the free speech mode failures are below:

Tester spoke: select automatic inventory
Computer: so let ought to manage in the Tory

Tester spoke: select automatic inventory
Computer: feather that I had a inventory

Tester spoke: select fantastic
Computer: slow lack didn't have that

Tester spoke: select fantastic success
Computer: The lack and passed the success

Tester spoke: Accuracy of representing dictation was, at best 50%, and most sentences made absolutely no sense.
Computer: Act receivers presenting dictation was, at best 50%, and most centers is made absolute nonsense.

The next step is to develop a limited language set with specific functions allowing the dynamic switching of small vocabularies. This will help the language software accuracy rate [Najjar], and speed up any task for which the WEVAC will be used. The WEVAC will contain several language sets that will be applied to specific applications and environments.

4. Collaborative Software

Another type of software that is essential to the successful operation of a WEVAC is collaborative. Many of the envisioned applications for this unit involve the user having conferencing capabilities with another person or group. The selection process was similar to that of the speech package choice. This time, four packages were tested: Microsoft NetMeeting, I-Visit, CU-SeeMe, and Clearphone. The factors for the evaluation of these packages are listed in the table below:

Collaborative Software Evaluation

Averages from surveys

Test	Netmeeting	I-Visit	Clearphone	CU-Seeme
Installation time (in minutes)	4 minutes	4 minutes	14 minutes	6 minutes
Installation difficulty (1=very difficult)	9	9	6	6
Installation clarity (regardless of time/difficulty) (1=very unclear)	10	9	6	6
Video picture quality? (1-no video, 10-excellent)	8	7	N/A	7
Video speed (1-very slow, 10-very fast)	7	7	N/A	4
Audio clarity (1-no audio 10-excellent)	8	6	7	5
Affect on machine performance (1=very slow)	9	9	N/A	8
Ease of general use. (1=very difficult, 10-easy)	10	8	8	4
Ease of program sharing (1-very difficult, 10-very easy)	9	N/A	N/A	N/A
Ease of chat box (1-difficult, 10-easy)	9	9	N/A	9
Ease of notepad/whiteboard (1-difficult, 10-easy)	9	N/A	N/A	N/A
Ease of file transfer/display? (1-difficult, 10-easy)	9	N/A	N/A	N/A
Overall rating? (1-unsatisfactory, 10-excellent)	**9**	**7**	**3**	**5**

General Comments

- All used Logitech QuickCam cameras.
- All microphones were one of Telex H-531, Plantronics and Labtec LVA-8420
- All machines ran at a CPU frequency of 350 MHz or greater.
- All machines had between 64 and 128 megabytes of RAM

Comments for Specific Packages

- Clearphone did not support video on PC's.
- Clearphone required the download of quicktime and moviegrabber.
- I-Visit only offered one special type of file for transferring.
- CU-seeMe's professional version did not arrive in time to be considered.
- CU-seeMe had no installation process, consequently, any icons or menu entries had to be manually created.

The audio/video capabilities, features, ease-of-use, and other evaluation factors determined that NetMeeting was preferred for collaborative software on the WEVAC.

5. Hardware

After the software was chosen for the WEVAC, hardware had to be procured and assembled to create the prototype unit.

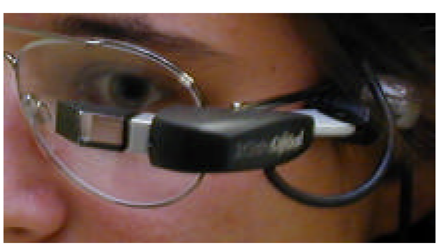
5.1. System Unit

For the actual system unit, we had several specifications to consider. We wanted a processor with a speed of at least 400 MHz and 64 MB RAM. These specifications, especially the RAM, were minimums because of the kind of video and voice capabilities and the software that must be installed. We also knew that we would need a USB port for an external mouse/trackball, a PCMCIA port for a wireless LAN connection, and a large enough hard drive to handle all of our applications comfortably. After much research and deliberation, two units were chosen: the Sony Picturebook and the SaintSong Pocket PC.

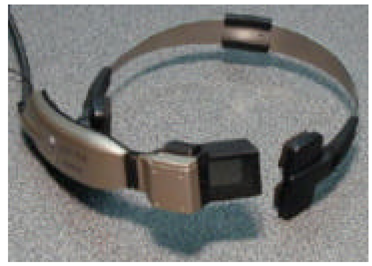
The Sony Picturebook offers all of the features that we wanted for our unit. It is lightweight, has a 400 MHz processor, 128 MB of RAM (upgraded), a USB port, a PCMCIA slot, and a 6 GB hard drive. The only drawback is that as a notebook it already has a display; the WEVAC team had envisioned a unit with a heads-up display for the user interface. Luckily, there is an external port for VGA that can be used for any display. This unit had a price tag of around $2000.

The second unit, the Saintsong Pocket PC, boasts a 533 MHz processor, 64 MB of RAM, a 4 GB hard drive, and two USB ports. This unit is also very lightweight (2.2 lbs.) and lacks a visual display of its own. This makes it a good fit for our wearable computer. There are two main drawbacks with the SaintSong unit however. First, there is no battery currently available for this unit which hinders its ability to be part of a completely mobile system. Second, the SaintSong unit lacks a PCMCIA slot, so we have no means of accessing the wireless network. Still, this unit's size and functionality make it an intriguing piece of equipment from which we can still learn a great deal. Combined with some of the Picturebook's features, this unit could be the future of WEVAC.

5.2. Displays



At the very heart of the WEVAC concept is the head-mounted display. The WEVAC team wanted to find a lightweight, VGA-compliant unit that would give a readable display without impairing the peripheral vision of the user. The team felt that 640 x 480 pixel resolution was the lowest level resolution that would yield positive results from users. Considering these factors, two displays were chosen: the MicroOptical clip-on display and the Olympus Eye-trek. The MicroOptical unit has only 320 x 240 pixel (QVGA) resolution, but offers superior peripheral vision for the user, optimizing the ability to see the work environment while using the display. It is extremely lightweight and can be used in conjunction with everyday eyeglasses. MicroOptical has plans to release a 640x480 version very soon.



The Eye-trek has great resolution (800 x 600 pixels) but has three drawbacks. First, the unit inhibits some of the vision, covering a larger portion of one of the user's eyes. Second, our prototype version required a separate PCMCIA adapter from Margi Systems. This arrangement added a display (i.e. it was not the main display). This means that program windows have to be dragged into the extension to be seen, making this unit more difficult to use. Olympus is working on a straight VGA conversion unit that should rectify this situation. Third, it needed an extra power lead, requiring extra effort to integrate into the wearable computer. However, the resolution of this unit is impressive.

In the near future, the WEVAC team envisions a heads-up display, which has both the weight and visual freedom of MicroOptical Corporation's clip-on display and the superior resolution of the Olympus display.

5.3. Wireless Communication

The WEVAC group decided to use the 802.11 standard for wireless local area networking. The IEEE 802.11 standard supports transmission in infrared light and two types of radio transmission within the unlicensed 2.4GHz frequency band. This allows for a range of 200 to 600 feet in real world applications, without the interference experienced with the 900 MHz range.

The use of wireless networking presents possible concerns with unauthorized access, data integrity, password interception, and session hijacking. We settled on the Cisco and Lucent products utilizing spread spectrum technology that was designed to be resistant to unauthorized access and interference. The Lucent WaveLan product offers two levels of data encryption, 64-bit and 128-bit keys. However, using encryption reduced data throughput. Cisco products require a service set identifier (SSID) code with over 16 million possible values; no wireless client can access the RF wireless network unless they have the correct SSID security codes. In addition, wired equivalency privacy (WEP) is used to ensure that captured RF waves cannot be intercepted for content or potential modification. To ensure the integrity of the data, 128-bit key encryption is used to encrypt the data before it is transmitted through the airwaves. Any packets received by the wireless network that are not encrypted with a valid key will be discarded.

The future of wireless technology will bring increased data rates (from the current 11 Mbps). This increase is needed to provide better quality video and audio in a collaborative environment. Firewire wireless appears to be on the horizon. The WEVAC project will test this technology when it is available.

5.4. Video Cameras

The last area, which is still being explored, is the video camera that will allow the user of the wearable computer to share what is seen with other collaborators. The fixed focal length cameras (non-zoom) are small, light weight, and use little power. However, they often produce a bowing effect that at times can misrepresent the subject. Technically, this occurs when the focal length is less than 50mm (when equated to a 35mm camera). It is very noticeable when the focal length is less than 30mm. The (optical) zoom cameras are much better because they can typically adjust to the natural focal length (50mm) and beyond, which naturally flattens out the bowing effect, so images are natural (i.e. like the human eye). Unfortunately, they weigh more than fixed focal length cameras, and require an external power source. On a wearable computer, these are very limiting factors. At this time the WEVAC engineers are communicating our form factor and weight concerns to the vendors of these cameras and encouraging them to improve their current models.

6. SUMMARY/FUTURE ENDEAVORS

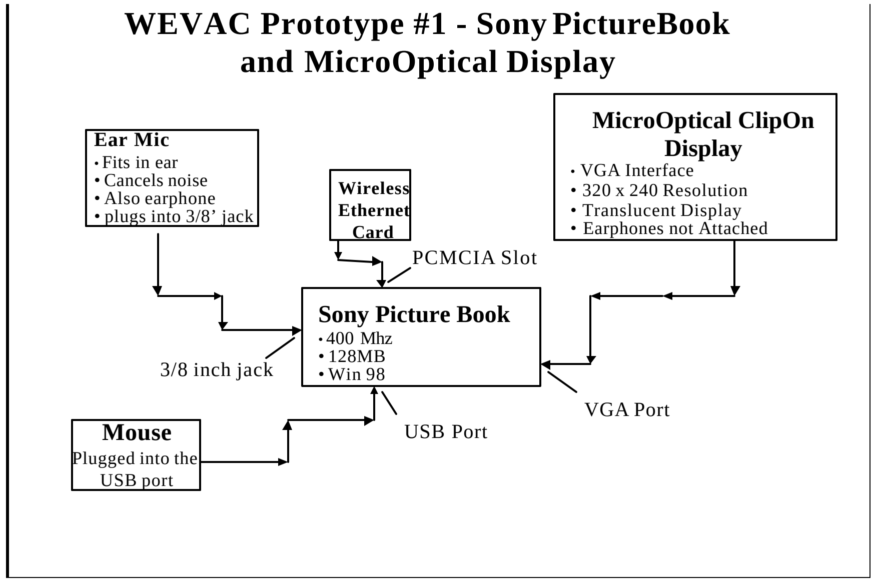
We have assembled a prototype unit linking the Picturebook and the Micro-optical clip-on display. Figure 1 shows the layout of this system. This unit was demonstrated by the project's two summer students, Daniel Green and Becky Williams. This WEVAC had full wireless capability and enabled the user to operate relatively easily with the Windows 98 operating system.

However, many challenges lie ahead for this project. Speech recognition development will be a large area of study for the future. It will be necessary to develop specific vocabularies for the speech package, which will aid recognition. To develop these vocabularies, domain analysis will be performed on NASA environments. This will help produce grammars that will facilitate the speech recognition rates. We have proposed a research project to develop a process to reduce the time required to create these custom vocabularies and grammars. To speed up development, our language development process will involve tools for language generalization so that similar environments can share a generalized description of a language. This language development process can be used to quickly generate other similar verbal languages. Also, it will be critical to find ways to minimize the intrusion to the user of the WEVAC. Another area still to be explored is battery life. Private industry is working on several different solutions for commercial users and the WEVAC project hopes to leverage this into a 6 to 8 hour life for the WEVAC batteries. Currently, the prototype is relatively large, but once prototype models are available for testing, the human factors engineering effort will dictate the changes to its current form that are most important to the users. Obviously, one area of effort is to gain more funding for future prototypes and more equipment. The WEVAC team also hopes to find other environments here at Goddard and other NASA sites in which to test the capabilities of our units. This will ensure thorough testing and broad applicability.

Figure 1 – WEVAC Prototype #1

7. REFERENCES

[Bently01] http://science.ksc.nasa.gov/payload/projects/borg/



[Bently02] http://science.ksc.nasa.gov/payload/projects/borg/shuttle.html

[Bently03] http://science.ksc.nasa.gov/payload/projects/borg/station.html

[Kortuem] "Some Issues in the Design of User-Interfaces for Collaborative Wearable Computers" - Gerd Kortuem, University of Oregon. The URL is: http://www.hitl.washington.edu/people/grof/VRAIS98/Kortuem.html

[Najjar] "User Interface Design Guidelines for Speech Recognition Applications" - Lawrence J. Najjar, Jennifer J. Ockerman, and J. Christopher Thompson. The URL is: http://www.hitl.washington.edu/people/grof/VRAIS98/chrisSpeech_recog.html

[Ockerman] "Wearable computers for performance support: Initial feasibility study" Jennifer J. Ockerman, Lawrence J. Najjar and J. Christopher Thompson. First International Symposium on Wearable Computers." (pp. 10-17). Los Alamitos, CA: IEEE Computer Society. http://mime1.gtri.gatech.edu/MiME/papers/ISWC_Jenn.html

[Roy] "Wearable Audio Computing: A Survey of Interaction Techniques" Deb Roy, Nitin Sawhney, Chris Schmandt and Alex Pentland. http://www.media.mit.edu/~nitin/NomadicRadio/AudioWearables.html

[WEVAC01] The summary report for the collaborative software testing evaluations can be viewed at the following URL: http://www.wff.nasa.gov/~WEVAC/Documents/collaborative_test_report.htm

[WEVAC02] The report justifying the choice in hardware can be viewed at the following URL: http://www.wff.nasa.gov/~WEVAC/Documents/Justification_hw.htm

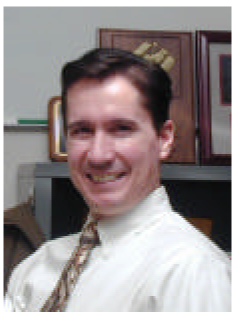
[WEVAC03] These along with other documentation can be viewed from the web site, which includes links to corporate sites for all hardware and software used for the WEVAC project and all products mentioned in this paper. This URL is: http://www.wff.nasa.gov/~WEVAC/index.html

8. Biographies

Barbara Pfarr is the Head of Goddard Space Flight

Center's Real-Time Software Engineering Branch, which develops Command and Control systems for integration and test and on-orbit operations of Earth and space science missions. This branch includes approximately 55 people working at both Wallops Flight Facility and Greenbelt. This includes a large variety of projects and systems, such as Hubble Space Telescope, Small and Medium Explorer Missions, Landsat 7, Triana, Terra and Aqua, EO-1, Sounding Rockets, and Ultra-long Duration Balloons. She received Goddard's Outstanding Management Award in 1999. Prior to this, she was the Hubble Space Telescope

Observatory Management Systems (HSTOMS) Manager, responsible for development and maintenance support of the Hubble ground systems at Goddard. She received NASA's Spaceflight Awareness Award and Goddard's Exceptional Achievement Award for these efforts. She received a B.A. in mathematics and astronomy from Smith College in 1981, a M.S. in Computer Science (concentration: Artificial Intelligence) from Johns Hopkins in 1991, and a M.S. in Computer Science (concentration: Graphics) from George Washington University in 1998.



Mark W. Rice is a consultant from Korson-McGregor who is leading this project. His project leadership and software mentoring/instruction skills have been proven within NASA and other organizations. He has many years of experience with every step of a system lifecycle, from proposal to final system approval, to training and long-term maintenance. Mark has a Bachelor of Science in Computer Science from Southern Adventist University and a Master of Science in Computer Science from Clemson University.

Curtis Fatig is the lead Hubble Space Telescope Servicing Mission Test and Integration Engineer. His team of engineers set up remote Payload Operations Centers, test the entire ground and space software and communication links used for each HST servicing mission, and test NASA institutional upgrades affecting HST. He also supports long term development of new mission ground systems. He received NASA's Spaceflight Awareness Award and many Achievement Awards for these efforts from GSFC, KSC and JSC. He received a B.S. from Salisbury State College in 1978 and a M.Ed. from Rollins College in 1982.

Daniel Green is a student at the Georgia Institute of Technology, majoring in electrical engineering. He attended Morehouse College from 1997 until Fall of 2000. He worked at Goddard Space Flight Center in the summer of 2000 as a Morehouse College Project Space Intern. Daniel is demonstrating WEVAC Prototype #1 in this photo.